# Model Linkages for Planning and Operational Systems Analysis at a Daily Time Step

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## ABSTRACT

Economic, social, environmental and physical constraints together with associated legal aspects introduced in the National Water Act (1998) are resulting in increasing emphasis being placed on improving water management in order to optimise water resource yields. However, in water resource planning and management there are often disparities between the analysis of the system done for planning and the actual operational management of the system. As a result improved management of the system is often difficult to achieve in practice. A contributing factor to discrepancies between planning and operational management is the temporal and spatial resolution with which processes occur and how they are represented in planning scenarios, i.e. planning is normally done at a monthly timestep, the actual operation of a system is often performed at a weekly timestep and natural physical processes occur at sub-daily timesteps. Thus the hypothesis presented here is that more detailed spatial and temporal scale modelling and decision support systems are needed in order to improve integrated water resources management and operations.

In this paper linkages between daily physical-conceptual models of hydrology and irrigation and a daily timestep network analysis systems model, are explored. The objectives of the paper are: (i) to discuss the rationale and advantages of running a planning model at a higher spatial and temporal resolution to more accurately reflect the operational management and physical processes occurring in a water resources system, and (ii) to assess whether the integration of the three types of modelling systems can be achieved in practice.

## 1 INTRODUCTION

The movement away from a riparian rights system adopted in the 1956 Water Act to the licensing system being used in the National Water Act (1998) is placing greater focus on individual water rights (or water use entitlements, the right to use the nations water resource). Added to this the requirement to consider environmental impacts and the ideal of a more decentralised management philosophy requires information to be provided to individuals and water managers at a finer temporal and spatial scale than was previously required. Physical and economic constraints are forcing a paradigm shift where water scarcity problems can no longer be addressed by supply side solutions. The focus has shifted to better operational management solutions to improve assurance of supply and make more water available to users. These factors are contributing to the requirement for decision support systems which operate at higher spatial and temporal resolutions to be deployed in catchments throughout South Africa.

In Water Resource Planning and Management disparities often appear between the planning analysis for water resource system and the actual operational management of the systems. A contributing factor to these discrepancies is often the temporal and spatial resolution with which processes are represented in planning scenarios (monthly), the actual operation of a system (weekly) and natural physical processes (daily or sub-daily). Improvements in data collection facilities, data storage programs, software programs and other information technology advances have made modelling at a daily time step a potential reality for water resource system planning and operations. This means that analyses done for planning can better reflect the operational management of the system and there is potential for such models to be used effectively for the real time operation of systems on a daily, weekly or monthly basis. In this paper the advantages of exploiting some of these advances in technology by coupling a hydrological model (ACRU), with a operational systems model (MIKE BASIN) and an irrigation systems and crop yield model (*ZIMsched 2.0*) at a daily scale, are explored. The main objectives of this paper are thus to:

- Discuss the rationale for looking at the linkages between these three models by identifying weaknesses with the current approaches and requirements from the perspective of the National Water Act
- Explore the conceptual and practical aspects of linking these models and assess whether the linkages are achievable.

## 2 RATIONALE FOR MOVING TO A MORE DETAILED DECISION MAKING FRAMEWORK

The main rationale for moving to a higher spatial resolution and finer temporal scale than existing planning and operational modelling activities are explored in this section. The initial focus is on some of the paradigm changes associated with the drafting of the NWA (1998) and the challenges associated with its implementation. The physical and economic constraints which are resulting in a paradigm shift are also discussed. The latter part of this section focuses on some concerns with current hydrological and water availability assessment approaches that are being used in South Africa.

### 2.1 National water act: A move from riparian based rights to a licensing system

The changes in the South African Government in 1994 and associated political and social upheavals resulted in the requirement to move to a National Water Act that must ensure a more representative equitable use of water throughout South Africa. Added to this political motivation was the physical problem of increasing water scarcity as a consequence of increased economic development and population growth. This situation is exacerbated by the uneven distribution of the resource. The Water Act of 1956 with its riparian rights principle would have reinforced the existing water usage distribution pattern. The riparian rights situation also leads to concerns about the economic efficiency produced by water use activities as upstream users can use water at the expense of downstream users in a system (Perkins and Seetal, 2004). Added to the political and economic concerns are the environmental issues, especially in stressed catchments, where it is possible that uncontrolled developments could have lead to the compromising of the ecosystem integrity which would have resulted in loss of ecosystem services thus compromising the long term sustainability of a water resource system. In order to address these and other concerns the drafters of the National Water Act (1998) decided to move away from a riparian rights structure to a licensing system.

The National Water Act (1998) is also promoting a more decentralised management philosophy with the formation of Catchment Management Agencies (CMAs). This requires far more stakeholder involvement in water management decisions with information needing to be effectively communicated to the individuals and organisations concerned. This requires water entitlements to be locally relevant and meaningful to individuals and that water management decisions are communicated to stakeholders within their own decision making time frame. In the operational context of catchment water management, commercial enterprise and irrigation decisions related to water supply and demand are typically made at a weekly or daily timescale. Added to this is the requirement to protect the environment with more detailed operating rules that maintain the resource variability, quality and quantity at a suitable level to sustain the ecosystem and the associated services and benefits it delivers.

These factors combined are placing more emphasis on more effective management of water systems and are moving away from the supply side solutions which have often been successful in the past. There is thus a need from a NWA perspective in the operational context to move to more detailed modelling approaches that reflect the actual operational decision-making and natural processes which take place within a catchment. Planning activities should also better represent the operational aspects in catchments as differences between the operations of a water supply system and planning estimates can cause large discrepancies from a water availability perspective.

### 2.2 Constraints: Factors pushing SA toward effective water management solutions

In South Africa the development of towns, cities and various other commercial and industrial centres has not followed typical spatial patterns developing around water resources as found in many parts of the world. Rather, the mining dominated economy has resulted in the manipulation of human, financial and material resources to develop according to a social and economic scenario which favoured the development of water resources along irrigation, mining and synthetic fuels production (Barta, 1999). The result is that from a spatial perspective there is a mismatch between water availability and supply. Added to this are the strongly seasonal and high inter-annual rainfall and runoff variability patterns in Southern Africa (Haines, *et al*., 1988; Schulze, 1997) resulting in a disparity between temporal water supply and actual water demand patterns. In the past the spatial and temporal disparities have been addressed through fairly effective supply side measures, mainly dominated by the construction of large dams and transfer schemes (Barta, 1999).

However, high intra and inter-annual climate variability requires that South Africa develops larger water related infrastructure and distribution schemes to maintain the same level level of water resource system yields as many other areas in the world (Chiew *et al*, 1997). The consequence is that in South Africa it is more expensive to obtain the same reliability of supply from its water resources systems when compared to many other countries. Adding to this problem most of the viable dam sites have already been developed and the capacity of existing systems is decreasing due to sedimentation. The combination of these factors makes water related supply schemes either extremely expensive or completely economically unviable.

These physical and economic constraints are thus leading to a paradigm shift which is looking to effective management solutions, to improve the water use efficiency and make more water available from existing water resource systems. The focus is thus moving away from a supply side management and planning operations to more effective daily, weekly and monthly operations of water resource systems.

## 2.3 Water use estimates: Are they good enough?

Historical, present and projected water use information is an essential part of Integrated Water Resources Planning (IWRP). The IWRP directorate in DWAF requires historical and present water use estimates to perform a number of key activities in the planning and allocations process, namely:

- Flow naturalisation: which requires good historical land and water use information which is then used to produce statistically stationary streamflow records, which are used for stochastic streamflow generation and for calculating the Instream Flow Requirements (IFR)
- Water demand pattern estimates: which require good existing and historical water usage estimates to work out the water use profiles of different water use sectors or activities, such as irrigation, industry and strategic use, as input into the yield and planning models to work out the systems yield and the reliability of supply for different users.

During the course of work being undertaken for the verification of existing lawful use projects in the Mhlathuze catchment and the Oliphants/Nkomati WMA it became clear that disparities existed between actual water use and the water use entitlement. This seems particularly prevalent in wetter areas where irrigation is used in a supplementary context.

While, some of these discrepancies can be explained by financial, logistical and other constraints not considered in an irrigation analysis, many of them are more a result of the assumptions used in the irrigation water use assessment approaches. The following list goes through some of the assumptions and more practical perceived realities associated with irrigation assessments.

| Assumption |
| --- |
| Irrigators use water to maximise crop yields |
| Reality |
| Irrigators often use less water than what is required to maximise crop yields |

| Assumption |
| --- |
| Irrigators follow the same level of assurance ascribed to them by DWAF and associated with their water use |
| Reality |
| Irrigators use their allocation to control their own reliability of supply often not using the full amount of water during wet periods but using their full restricted quota during drier periods |

In the authors opinion this assumption results in the largest discrepancies between actual water use and the irrigation allocations particularly in wetter regions of the country. The difference relates to the current water management paradigm which limits irrigators' water requirements through restriction rules when they require their water the most. The result is that irrigators often apply for or are provided with permits/licenses (water use entitlement) that are greater than their actual mean water requirement. The consequence is that during wet periods they use far less water than they are entitled to but in drier periods when they are restricted they use their full quota that they need or are short of water. This methodology effectively enables them to increase the level of assurance of their water supply and reduce their risk. This is explained in more detail in the simplified conceptual diagram shown in Figure 2.1 as an example. In the Figure the actual allocation profile represented by the blue area is not used what is actually used by the irrigator, the actual irrigation requirement (actual use) in the wetter period is 50% of the irrigation quota and it is represented by the red line which reflects the irrigator's actual water use. The consequence is that the irrigator/user manages to improve the assurance of supply getting 100 % of what is requires 90% or the time instead of 70% of the time if the allocation profile was followed. The consequence is that water use from an allocations perspective is overestimated in wet periods if modellers base their modelling on the allocations.

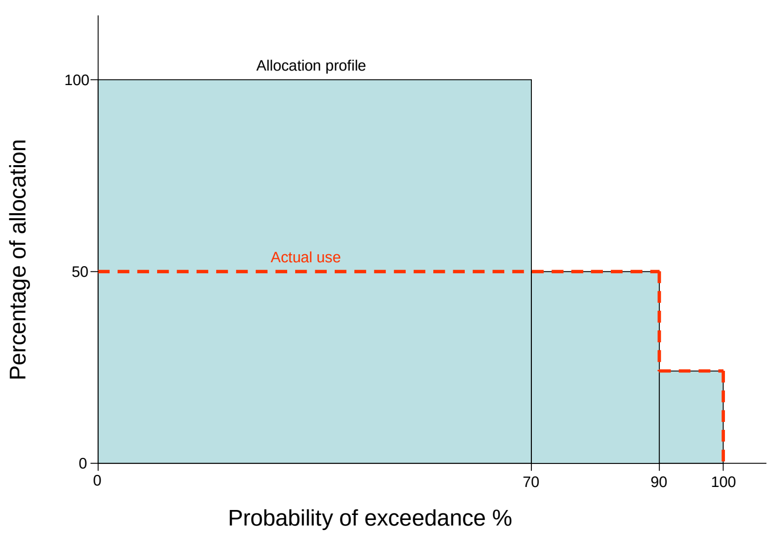


**Figure 2.1: Conceptual diagram of actual versus allocated water use for an irrigator**

| Assumption |
| --- |
| Current, aggregated monthly irrigation modelling can represent daily irrigation water supply and demand patterns adequately |
| Reality |
| Daily irrigation demand, and water availability patterns have a large influence on irrigation water use and these are often not reflected accurately in the aggregated monthly time-step irrigation modelling |

The irrigation requirement fluctuates on a daily basis according to weather related variables. While irrigators in many areas follow a set irrigation routine they will interrupt or modify this routine if weather conditions change. Information technology and improvements in irrigation system controls are enabling some irrigators to improve their water use by modifying their irrigation practice according to weather patterns. The daily weather patterns and associated changes in water demand are not captured in monthly irrigation modelling estimates. Furthermore, the potential hydrological implications of improved irrigation water management are not easily captured nor represented.

Added to this the daily water availability particularly in run of river systems is not considered in the monthly modelling approaches. This averaging of monthly flows allows irrigators access to water they may not have been able to use on a daily basis. This is especially true in quicker response (headwater) catchments where streamflow fluctuates on a week- by - week basis can be substantial, for example on the Little Tugela. However, this can also be the case in controlled catchments where water users may not be in a position to extract all the water being released due to timing problems.

| Assumption |
| --- |
| Feedback mechanisms such as return flows and water demand patterns can be accurately captured by current monthly irrigation modelling practices |
| Reality |
| Irrigation water use fluctuates from day to day, even if the irrigator applies the same amount to the field every day the actual irrigation return flows and amounts reaching the base flow storage differ from day to day and these may not be captured by monthly approximations. Irrigation water demand fluctuates on a daily basis due to weather considerations, in time of scarcity the amount of irrigation applied in one cycle affects the water demand and potential return flows in the next irrigation cycle. |

Irrigation return flow can vary considerably according to the prevailing weather conditions within a catchment area on any given day. Even if the same irrigation amounts are applied the actual crop water use varies according to cloud cover, precipitation, temperature, wind and other factors. This influences the amount of water reaching the groundwater supply and it is doubtful that these interactions and nuances are captured in the monthly modelling approached currently employed resulting in poor estimates of return flows. Return flow can have a major impact on water availability and quality and thus supply to downstream users. Again the potential impact on return flows of improved irrigation efficiencies should be investigated in an integrated water resources management context. This will likely require more detailed representation of the irrigation processes than what can be achieved when modelling at a monthly time-step.

Added to this are the feedback mechanisms resulting from irrigation water applications which are difficult to represent in the monthly modelling approach. The inability to use water on one particular day influences the irrigation demand on the following day as the water deficit is increased. It will also reduce the return flow the following day as the soil water deficit will have increased requiring more irrigation to supply the plants needs resulting in less interflow and less water reaching the base flow store.

It is important to recognise the outlined pitfalls in terms of water use patterns as they can have a significant impact on predicted (modelled) water availability status in catchments. Firstly, incorrect usage estimates can influence the naturalisation process leading to biased non-stationary naturalised streamflow estimates and skewed streamflow estimates. Secondly, the over estimation of actual water use could lead to less water being made available for other water users having social and economic implications. Thirdly, underestimates of water usage could result in more water being made available and compromising the assurance of supply of existing users on the system.

It is likely that a more detailed irrigation simulation modelling approach as discussed in this paper could resolve some of these concerns and would lead to better estimates of actual irrigation water supply and demand interactions for both operational and planning analyses.

## 2.4 Naturalisation: Are we considering the hydrology adequately?

In most areas in South Africa the influence of catchment developments (including: irrigation, landuse changes, transfers, small dams) on runoff is significant. In catchments where developments have a noticeable impact on runoff it is necessary to identify all such developments and establish the influence that each has had on the streamflow record. The process of accounting for such developments is referred to as streamflow naturalisation and is one of the processes which can result in a so-called natural and virgin flow record (McKenzie and van Rooyen, 1999). The rationale for obtaining natural or virgin flow records includes:

- Firstly, to obtain a stationary streamflow sequence that can be used in the generation of stochastic streamflow sequences, and
- Secondly, to obtain a record of the natural flow sequence so that it can be used in assisting with the approximation of the environmental reserve.

The rationale needed to obtain a natural or virgin streamflow record is clear, however, the process used to obtain such records is fraught with difficulties. Currently, flow naturalisation is undertaken using the Pitman monthly model or hybrid versions of the Piman model (WRSM2000). Typically the model is calibrated using a relatively short period of observed streamflows. Estimated water demands are then added to obtain the 'natural' flow and the simulation period extended. The main concern in the current methodology is the uncertainty involved in properly accounting for all the influences of catchment developments. Given the problems associated with estimating existing water use patterns in South Africa and the paucity of historical information on water usage and landuse patterns, estimating the influence of catchment developments on runoff is extremely difficult and thus the model is often calibrated to give 'right' answers for the wrong reasons.

Currently, the main focus on estimating catchment developments advocated in the WRSM 2000/Pitman approaches has focussed mainly on afforestation, alien vegetation and diffuse irrigation water use. However, other anthropogenic interventions such as different tillage practices (especially zero-till), landuse/cover changes and groundwater use can also have a significant impact on runoff patterns. While, the WR2005 project is looking to address some of these issues, current naturalised hydrological sequences probably do not reflect these influences and it is questionable whether assessments based on a non – integrated modelling approach will represent these influences adequately. While, the Pitman model has some physical basis it is primarily a calibration approach and it is difficult to predict how the influence of landuse changes such as different cropping practices will change the parameters as these are set by streamflow calibrations rather than by measurable observations of catchment physical characteristics. The approach also does not account for crop water use explicitly. The result is that it is difficult to predict the influence of landuse changes, irrigation management practices and other catchment developments using the model.

A key objective of the flow naturalisation process is to create stationary streamflow sequences. Therefore, testing for stationarity would reveal the success of the approach. A double mass analysis technique has been applied in many catchments throughout the country in the course of consulting work. Double mass analysis is a standard tool for screening and quality checking hydrological time series. If climate variation affects hydrological measurements at two closely located stations in a similar way or the hydrological time series is dependant on a relatively speaking stationary series such as rainfall, a double mass analysis of those stations should plot as an almost straight line. Non-linearity or bends are indications of changed conditions in (at least) one of the stations. Such changes may originate from poor/worsened measurement accuracy or from changed catchment conditions. The visual inspection of a double mass plot can be misleading and the technique of using regression residuals to determine if there are biases in the series is used.

The results of a double mass analysis technique applied to many hydrological catchments in the country reveals non-homogeneity in the hydrological time sequences when compared to rainfall in the area. Assuming that rainfall information is relatively stationary this indicates non-stationarity in the hydrological time series. An example of sequences showing this type of bias is provided in Figures 2.2 and 2.3. These sequences indicate that the naturalisation process is perhaps not effective in removing the influence of development trends within catchment areas. As one can see in Figure 2.3 the residuals are clearly not showing a random pattern indicating that there are biases in the naturalised hydrological record when compared to rainfall.

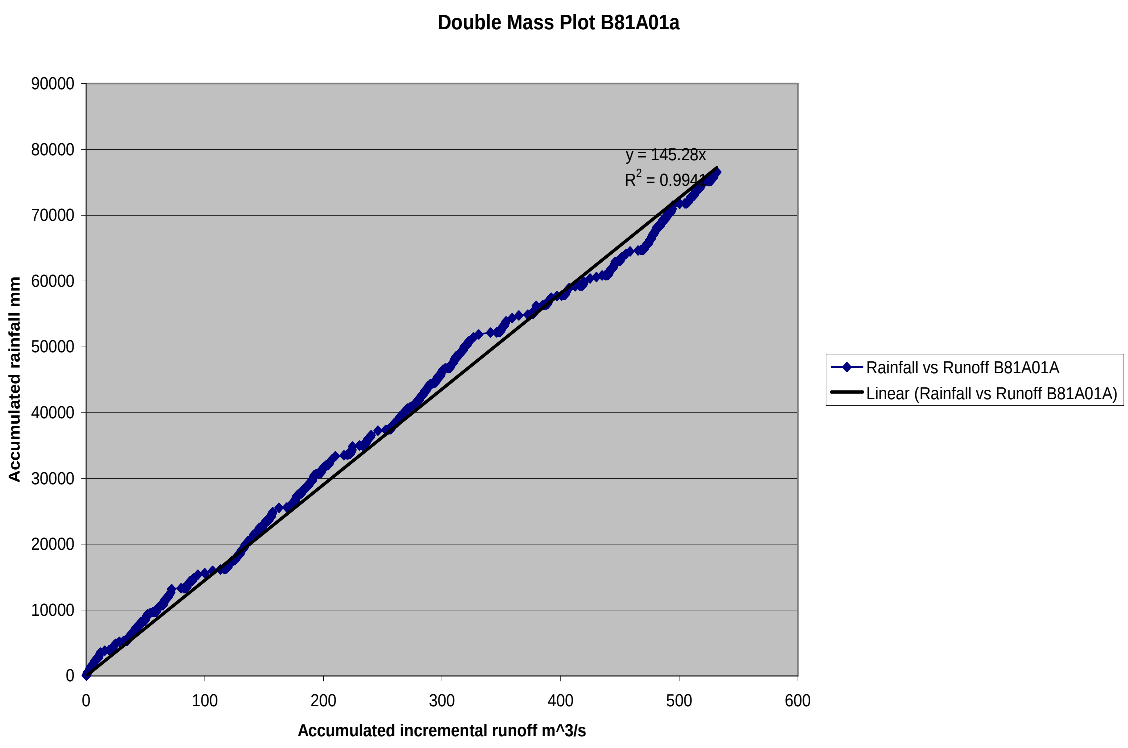


**Figure 2.2: Double mass plot for catchment area B81A01A above Dap Naude Dam**

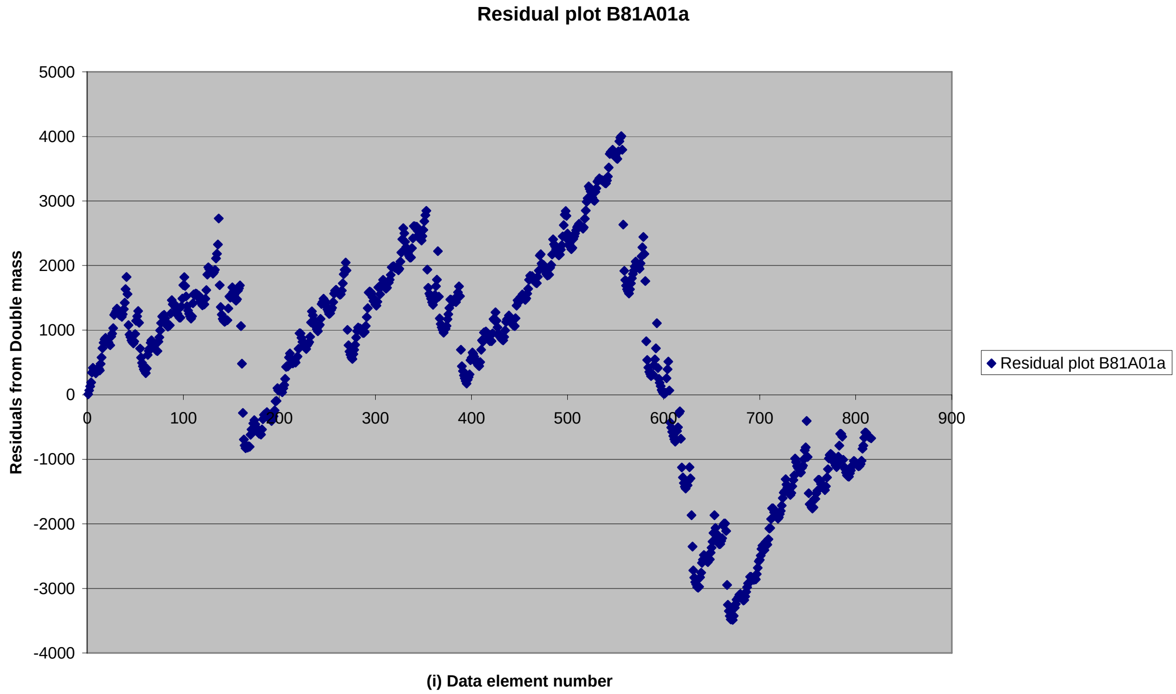


**Figure 2.3: Residual plot of the double mass analysis for B81A01A above Dap Naude Dam**

Another aspect of the naturalisation process is that it is unlikely to produce consistent estimates of natural or virgin streamflow as different people may model the influence of development trends differently. This inconsistency could result in debate over which estimates to use for the natural hydrology.

Another methodology to produce natural records would be to simulate a natural condition using a physical-conceptual hydrological model such as ACRU or SWAT. These models simulate the physical aspects of plant water usage and the water balance in a conceptually representative manner and can account for effects such as different cropping patterns and landuse management practices. Therefore, with these models there is no need to account for the impacts of uncertain historical water use and landuse changes as a catchment can be simulated under natural vegetation conditions. The Acocks (1988) vegetation maps or other similar maps could be used to produce ‘natural’ flow records and the results produced would be relatively consistent. Impacts of landuse change could then be simulated under current development or projected development patterns. While not perfect, a big advantage of this methodology is that it is likely to produce more consistent and stationary hydrological records for both developed and natural conditions and developments in the understanding of hydrological processes associated with different land covers and uses can be more easily incorporated and represented

## 2.5 Current stochastic methodologies: Are we considering the hydrology adequately?

The current stochastic streamflow generation methodology produces alternative annual stochastic sequences based on the naturalised hydrology then uses a representative year concept to disaggregate these sequences to plausible monthly values. Influences such as diffuse irrigation, afforestation, and specific demands are essentially ignored in the stochastics generation process and the representative year process is used to obtain a corresponding demand or water use sequence. Alternatively a duration curve is used to obtain this information. The current process thus essentially ignores the hydrological interactions and feedbacks within the catchment. Water use by irrigation or forestry is primarily a function of climate and is not highly correlated to streamflow, this means that such methods of estimation essentially ignore the hydrology in the catchment and could result in significantly skewed results.

It is recommended that the following aspects associated with the stochastic streamflow generation be explored. The strochastics should rather be performed on the rainfall sequences, which are relatively stationary and do not need to undergo naturalisation. The stochastic rainfall sequences should then be fed through a hydrological model which can account for the impacts of forestry, irrigation, and other land and water use practices explicitly. This method would then produce stochastic streamflow records in which hydrological interactions and feedbacks have been represented.

Alternatively, disturbed streamflow sequences under current or expected development conditions could be produced accounting for all the effects of forestry and other water uses. These could then be used to produce stochastic streamflow records. This methodology better accounts for the hydrology, however, not as explicitly as in the methodology described in the previous paragraph.

## 2.6 Main reasons for exploring the linkages between the different models

It is believed that the proposed linkage between the models will address some of the problems mentioned in the previous three sections. Added to this it is also believed that the linkages will provide the following advantages:

- Provide better planning estimates as:
  - The linked models can be 'run' on a daily basis thus providing better representation of actual operations
  - Irrigation demands and return flows will respond to climate and management drivers thus providing more realistic estimates of irrigation demand
  - Runoff interaction and impacts of landuse and management practices are taken into account with the hydrological model
  - The operational limitations and operating rules come into play curtailing users accordingly and preventing irrigation or other water uses from taking place on a daily or weekly timescale
  - The feedback between irrigation demand and supply is taken into account explicitly providing a better estimate of irrigation water use and return flows
- Provide improved operational management:
  - Information can be communicated with individual users and water managers effectively
  - Short term analysis and forecasts can be performed
  - The system can be updated and manipulated in near-real-time
  - Water availability is linked to irrigation requirements enabling farmers to test different management scenarios in both the short and long term

# 3 METHODOLOGY

One of the main objectives of this study was to identify if it was possible to integrate a physical-conceptual hydrological model, with a systems operation model and a physical-conceptual irrigation model to run at a daily basis to better reflect the operations and processes in a catchment. This could essentially be done using any number of different hydrological, systems or irrigation models however for this research the following three models where chosen (descriptions follow in this section) Mike Basin (DHI water and environment, 2003) (System model), ACRU (Schulze et al, 1995) (Hydrological Model) and *ZIMsched 2.0* (Lecler, 2003) (Irrigation Model). The reasons for this choice are as follows:

- ACRU has been developed and verified in a wide range of conditions in South Africa and thus physically representative parameters for a wide range of soils, land covers and land uses are readily available and have been verified
- MIKE BASIN is a system model which is designed to run on any time step greater than a second and thus it can easily be run on a daily basis. The model has also been designed with a Command Object Module (COM) interface which allows for easy manipulation of the internal parameters and time sequences. The COM interface facilitates linking with the other models. The new ARCGIS 9 version of the model is also moving toward the Harmon IT, Open MI standard which could also assist with complex model integrations.
- *ZIMsched 2.0* is based on the internationally recognised daily timestep, FAO 56 (Allen *et al*., 1998) irrigation crop water demand algorithms with refinements to represent stormflow, deep percolation, and impacts of irrigation management and system performance on sugarcane yields. SAPWAT (van Heerden et al., 2001) which is widely used and accepted in South Africa is based on a more simple and coarse version of the FAO 56 algorithms. Furthermore *ZIMsched 2.0* has been translated into Excel which enables easy manipulation of the model input and output parameters and facilitates linking to MIKE BASIN.

In Figure 3.1 a diagram showing the conceptual links between the models is presented. In the diagram it can be seen that the hydrological model (ACRU) is a sequential link meaning the model is set up from GIS then run for the entire time series or set of stochastic time series and this information is used for input into the systems models. The reason this is done is that feedback loop with the landbased hydrology is unnecessary as the feedback loop associated with the landbased hydrology is not as significant as that from irrigation (return flow and demands). The irrigation (*ZIMsched 2.0*) and Systems (MIKE BASIN) models are run in parallel with the irrigation demand information being fed to the system model on a daily basis, the demands are then curtailed according to the rules in the system models and information on actual amount that can be used by the irrigator is fed back to the irrigation model which then adjusts it demands accordingly for the next time step and provides information on the return flows back to the systems model. This is then repeated for each time step throughout the simulation.

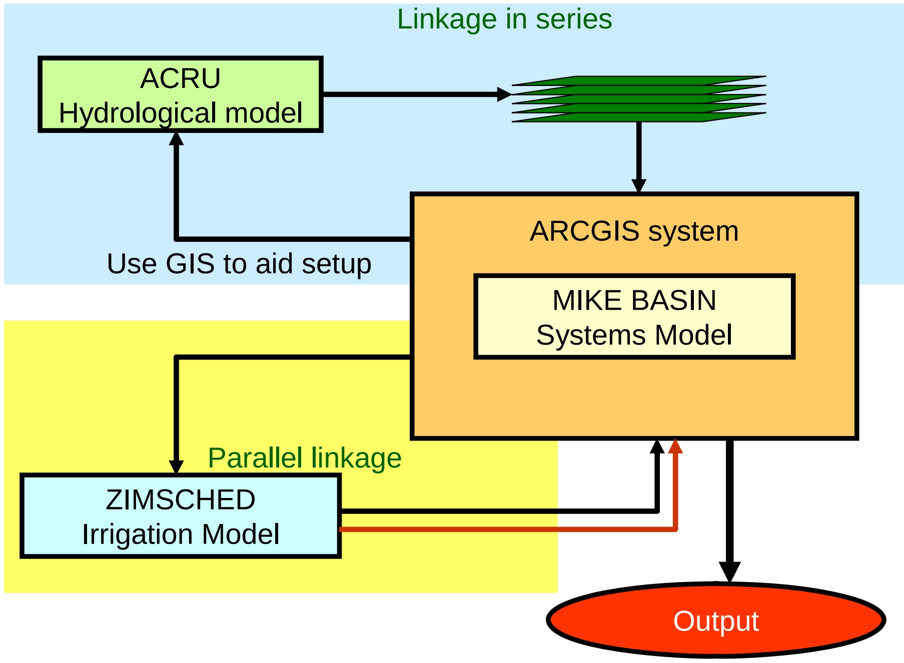


**Figure 3.1: Linkage between the models**

Rudimentary but operational links between the irrigation model (*ZIMsched 2.0*) and the operational system model (MIKE BASIN) have been established thus far. The link between the ACRU model and MIKE BASIN is still under development and it is anticipated that this will be ready by the time this paper is presented. Preliminary results of this link will thus be shown when the paper is presented.

### 3.1 MIKE BASIN

MIKE BASIN is a simulation model for water allocation representing the hydrology of the basin in space and time. Technically, it is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. The branches represent individual stream sections while the nodes represent confluences, diversions, locations where certain water activities may occur, or important locations where model results are required. MIKE BASIN uses a graphical user interface (GUI), which links the MIKE BASIN computational engine with ArcView GIS. The interface is developed in an ArcViewTM environment and works using the ArcViewTM functionality. The MIKE BASIN application uses a customized ArcViewTM GUI. Integration within the ArcView environment ensures that the full ArcView functionality is maintained (DHI Water and Environment, 2003).

MIKE BASIN’s computational core ("engine") can be accessed from Microsoft Excel macros (written in Visual Basic) or from any other program/programming language that supports the Microsoft COM technology (Visual C++, Delphi, C#, and others). Input to the model is instead specified directly in the macro/program. The approach is useful when having to run many MIKE BASIN simulations, but furthermore, it gives access to functionality not available from the user interface, because simulations can also be run one time step or even one iteration at a time (DHI Water and Environment, 2003) thus facilitating:

- Rapid sensitivity analysis through (many) Monte-Carlo simulations
- Rapid execution and analysis of multiple scenarios
- Post-processing of results (using Excel’s statistics functions or other)
- Optimization of any kind through Excel’s Solver tool (‘Data’ menu) or any other COM-supporting optimization software
- Implementation of any mechanism besides MIKE BASIN’s standard allocation algorithms (e.g., operation of inter-related multiple reservoirs).
- Dynamic simulation control (step-wise simulation, hotstart from any previous time step, or even iteration within a time step)
- Easy creation of simple Excel user interfaces to site-specific MIKE BASIN models (that can be executed also by non-GIS users)

### 3.2 ACRU

ACRU could be described as a physically based conceptual model in that it provides a conceptual model of important processes and couplings within the hydrological system and uses physical processes to represent them explicitly. The ACRU model revolves around daily multi layer soil water budgeting developed into a versatile total evaporation model that is capable of modeling the impacts that landuse and climate changes have on the soil water and runoff regimes. (Schulze et al, 1995)

### 3.3 *ZIMsched 2.0*

*ZIMsched 2.0* is a deterministic crop and irrigation systems simulation model. The model was developed in order to estimate how water management, different irrigation system characteristics and the infield measures of irrigation systems performance indices such as the coefficient of uniformity (CU) impact on potential crop yields and the water balance. (Lecler, 2003). *ZIMsched 2.0* is based largely on the algorithms described in the Food and Agriculture Organisation of the United Nations (FAO) Irrigation and Drainage Paper No. 56, by Allen *et al.* (1998) with refinements added to represent stormflow, drainage, irrigation system performance and sugarcane yield impacts. The *ZIMsched 2.0* model has been verified and applied successfully in Zimbabwe to estimate crop water use and sucrose yields from different irrigation systems under a wide range of water management and climate conditions (Lecler, 2003; Lecler and Griffiths, 2003). For this research, the model has recently been updated so that large spectrum of crops can be represented based on parameters given in the SAPWAT (or FAO 56) crop information database.

## 4 CONCLUSION

Concepts required to link a hydrological, irrigation systems and network analysis model to enable agro-hydrological simulations of catchment and water management processes on a daily time step have been developed. Rudimentary but functional links have also been established. The motivation for these linkages is that they could enable water managers and water users to model and assess impacts on the system at an operationally representative time and spatial scale. This should enable more realistic scenario analysis of catchment operations, which, it is argued will facilitate improved catchment management and potentially release more water for use at a more reliable assurance of supply. The more refined and representative operational rules and water use patterns could then be used to improve estimates of water supply and demand patterns in any given catchment which is necessary for better planning.

It is reasoned that there is a clear need for this level of modelling in the operational context where it could be used to improve the efficiency of water management. Furthermore, improved spatially and temporally representative and detailed modelling as has been proposed, could resolve some of the perceived problems associated with the water resource planning process. This is especially the case where operational management is not reflected accurately and water use and hydrological interactions are not represented explicitly. Furthermore, the linking of water supply constraints to water requirements at an operational time scale (daily or weekly) provides water users and water resource managers with more flexibility to test a number of scenarios in both the operational and planning context and thus more options/information to mitigate risks.

The preliminary investigations into linking the models are encouraging and the rationale for the linkages reasonably sound in the opinion of the authors. Nevertheless, it is acknowledged that case study applications and comparisons to alternative and more traditional water resources planning approaches are needed to help prove and make explicit many of the arguments presented in this paper.

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